

# Influence of collimator rotation on dose distribution and delivery in intensity modulated radiation therapy for parotid cancer

Seema Sharma, Durai Manigandan, Shikha Goyal, Puja Sahai, Velliyan Subramani,  
Subhash Chander, Pramod Kumar Julka, Goura Kishor Rath

Department of Radiation Oncology, All India Institute of Medical Sciences, New Delhi, India

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## Technical Report

### Abstract

**Purpose:** To evaluate the influence of collimator rotation in IMRT planning with respect to the target coverage and dose to critical structures. In addition, the delivery efficiency of desired fluence with collimator rotation is assessed. **Methods:** The computed tomography (CT) datasets of 5 patients with parotid cancer were employed for this study. Dynamic IMRT plans were generated with a dose prescription of 60 Gy in 30 fractions. IMRT plans were generated with five unilateral fields using 6MV X-rays. Four different plans were generated for each patient by keeping the collimator angle at 0, 30, 60, and 90 degree. All plans were analyzed using dose volume histogram. Conformity index (CI) and heterogeneity index (HI) were calculated. The total monitor units (MU) required to deliver one fraction were noted and compared. To verify the delivery efficiency; the measured fluence on IBA I'mRT MatriXX ionization chamber array detector was compared with the TPS dose plan with 2D gamma evaluation. **Results:** There is not much difference in the PTV Dmax and Dmean with respect to the different collimator angles. The PTV coverage is best at collimator angle of 0 degree. A slight reduction in CI was observed with plans at other collimator angles as compared to 0 degree. The HI values were almost similar for plans with collimator angle 0, 30, and 60 degree. The plan with 90 degree collimator showed a slightly higher heterogeneity for the PTV. A slight reduction in the average Dmax to spinal cord was observed for the plan with collimator angle 30 degree as compared to other angles whereas maximum value of Dmax to spinal cord was at collimator angle 60 degree. No clinically relevant difference was observed among the plans with respect to brainstem and mandible Dmax. An increase in average of oral cavity Dmax and Dmean was observed for collimator angle 60 and 90 degree as compared to collimator angle 0 and 30 degree. Not much difference was observed with respect to Dmax and Dmean for contralateral parotid and cochlea with plans at different collimator angles. A decrease in MU required to deliver a fraction was observed for the plan with collimator angle 30 degree as compared to other angles. The plan with 90 degree collimator required maximum MU. The 2D gamma index evaluation of planned and delivered fluence showed almost similar results for plans with different collimator angles. **Conclusion:** An individual case-specific collimator rotation may aid in achieving the desired dose distribution and relative sparing of critical structures in IMRT.

**Keywords:** Collimator Rotation; Intensity-Modulated Radiotherapy; Parotid Cancer

### Introduction

The advent of linear accelerator and multi-leaf collimator (MLC) has allowed achieving a conformal radiation treatment. With the movement of MLC, the intensity of beam is modulated. Intensity modulated radiation therapy (IMRT)<sup>1-5</sup> can be delivered in two ways i.e., dynamic and static. IMRT carries the potential to acquire the desired shape and gradient of dose distribution to achieve target conformity with fewer doses to normal structures. In the IMRT planning process, the number of fields, beam orientation, beam energy, couch rotation and other parameters are changed one by one for optimization to achieve the best dose distribution. The collimator rotation gives additional degree of freedom, however the planning and treatment delivery becomes complex. Yang

*et al.*<sup>6</sup> investigate the effects of collimator and couch angle change on the dose distribution for breast cancer treatment using intensity-modulated tangential photon beams and results showed that 4° change in the collimator angle or the couch angle did not affect the dose distribution significantly. Isa *et al.*<sup>7</sup> studied the dose-volume variations of planning target volume (PTV) and organs-at-risk (OARs) in prostate volumetric modulated arc therapy (VMAT) at different collimator angles (0°, 15°, 30°, 45°, 60°, 75°) using a Harold heterogeneous pelvis phantom. Results showed that PTV dose coverage for each plan was comparatively independent of the collimator angle. A higher CI (0.53) and lower HI (0.064) were found at 45° collimator angle and rectum sparing was

Corresponding author: Seema Sharma; Department of Radiation Oncology, All India Institute of Medical Sciences, New Delhi, India.

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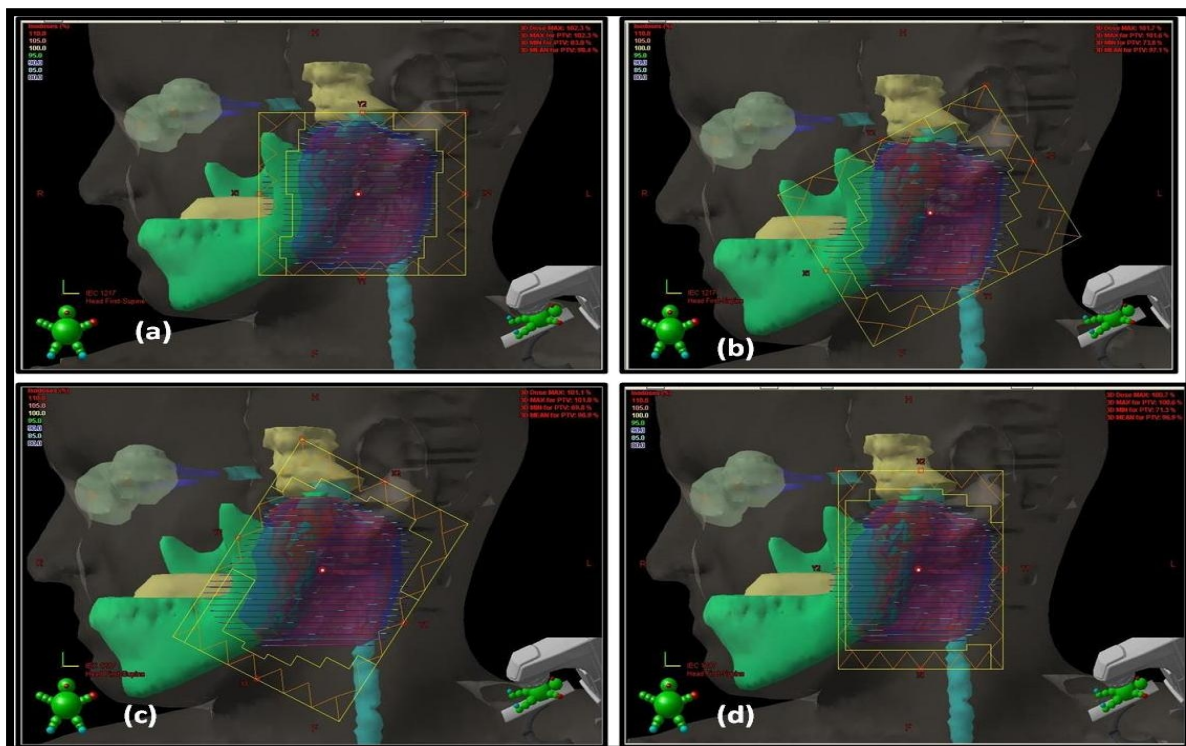
good at 75° and 90° collimator angle. In continuation of the above work we designed a study to evaluate the influence of collimator rotation in IMRT planning with respect to the target coverage and dose to critical structures for parotid cancer. In addition, the delivery efficiency of desired fluence with collimator rotation is assessed.

## Methods and Materials

The computed tomography (CT) datasets of 5 patients with parotid cancer were employed for this study. Post-operative radiotherapy was planned for these patients. The patients were immobilized with a thermoplastic cast with head turned towards contralateral side at 90 degree. The CT scan was performed with 3 mm slice thickness. The images were transferred to the Eclipse (Varian medical system, Palo Alto, CA, Helios version 6.5) treatment planning system (TPS) through DICOM. The delineation of clinical target volume (CTV), planning target volume (PTV), and organs at risk (OARs) viz., spinal cord, brainstem, contralateral parotid and cochlea, oral cavity, and mandible was performed. Dynamic IMRT plans were generated for Varian CL2300C/D linear accelerator. A dose of 60 Gy in 30 fractions was prescribed. The following dose volume constraints were specified: at least 95% of PTV to receive 95% of the prescribed dose, brainstem maximum dose (Dmax)  $\leq$  54Gy, spinal cord Dmax  $\leq$  45 Gy, contralateral cochlea mean dose (Dmean)  $\leq$  45Gy, contralateral parotid gland Dmean  $\leq$  26Gy, mandible Dmax  $\leq$  70Gy, and oral cavity Dmean  $\leq$  45Gy.

IMRT plans were generated with five unilateral fields using 6MV X-rays.<sup>8</sup> For dose calculation pencil beam dose calculation algorithm at 2.5mm grid resolution was used. During optimization smoothing parameters were kept as  $X = 40$ , and  $Y = 30$ . Four different plans were generated for each patient by changing the collimator angle from 0 to 90 degree in increment of 30 degree. Hence, the plans corresponded to the collimator angle of 0, 30, 60, and 90 degree. The process of optimization in the Eclipse TPS is random. Thus, to maintain the symmetry in generating plans, all plans were optimized and prescribed in a similar manner to get a valid comparison.

It was not possible to achieve similar optimization result even with same plan for same patient, to minimize this variation; a base plan was generated in which collimator angle and all other optimization parameters (i.e. dose constraints, priority settings etc.) were fully optimized. Then this base plan was saved as template plan. For generating plans for other collimator angles, fluence pattern was deleted from the template (or base) plan and only collimator angle was changed, by keeping all other parameters constant. IMRT optimization was continued until no further improvements were noticed in optimization graph. Similarly, this template plan was applied for other collimator angles also. The beam's eye view (BEV) for a representative patient with respect to the collimator angle 0, 30, 60, and 90 degree in shown in **Figure 1(a-d)**.



**FIG. 1(a-d):** The beam's eye view in a representative patient for collimator angle at 0 degree (a), 30 degree (b), 60 degree (c), and 90 degree (d).

### Plan evaluation

All plans were analyzed using dose volume histogram (DVH). The Dmax and Dmean to brainstem, contralateral parotid, contralateral cochlea, and oral cavity were noted. The Dmax to spinal cord and mandible was noted. The target was evaluated in terms of maximum, minimum, and mean dose. Conformity index (CI) and heterogeneity index (HI) were calculated to analyze the PTV dose coverage and homogeneity respectively.<sup>9-11</sup>

### Conformity index (CI)

CI is defined as the ratio of TV<sub>RI</sub> to TV.

$$CI = TV_{RI}/TV$$

TV<sub>RI</sub> = target volume covered by the reference isodose

TV = target volume

This index ranges from 0 to 1. The volume of adjacent healthy tissues is not taken into account in this index.

### Heterogeneity index (HI):

HI is defined as the ratio of D<sub>5%</sub> to D<sub>95%</sub> for the PTV.

$$HI = D_{5\%}/D_{95\%}$$

D<sub>5%</sub> = dose delivered to 5% of PTV volume

D<sub>95%</sub> = dose delivered to 95% of PTV volume

It is evident that if the value of heterogeneity index is closer to 1, the better will be the dose homogeneity for the PTV.

### Plan deliverability

The total monitor units (MU) required to deliver one fraction were noted and compared among the different plans.

### Measurement of planned and delivered fluence

The planned fluence was transferred to the previously scanned I'mRT MatriXX ionization chamber array (IBA Dosimetry, Scanditronix Wellhofer, Germany). The 4.7 cm slabs of virtual water phantom were placed above IBA I'mRT MatriXX ionization chamber array and 15 cm below as backscatter for measurement.

To verify the delivery efficiency, planned fluence was delivered to the IBA I'mRT MatriXX ionization chamber array detector. The measured fluence was compared with the TPS dose plan with OmniPro-I'mRT software (IBA Dosimetry, Scanditronix Wellhofer, Germany) using 2D Gamma index ( $\gamma$ ) as proposed by Low et al.<sup>12</sup> With regard to the reference gamma value for planned and delivered fluence evaluation, a criterion was set to 3% dose difference and 3 mm distance to agreement. The plan was accepted only if more than 95% pixels having the value of  $\gamma \leq 1$  and rejected when  $\gamma > 1$ .

## Results

The DVH evaluation results of PTV and OARs are tabulated in **Table 1**. There is no clinically significant difference in the PTV Dmax and Dmean with respect to the different collimator angles.

The average of CI and HI values for PTV with respect to the collimator angles 0 to 90 degree is listed in **Table 2**. The PTV coverage is best at collimator angle of 0 degree. A slight reduction in CI was observed with plans at other collimator angles as compared to 0 degree. However, the difference is not clinically significant. Therefore, collimator rotation does not compromise the PTV coverage. The HI values were almost similar for plans with collimator angle 0, 30, and 60 degree. The plan with 90 degree collimator showed a slightly higher heterogeneity for the PTV. However, there is no clinically significant difference between the plans with respect to HI. The dose volume comparison curve of PTV for a representative patient is shown in **Figure 2(a)**.

A slight reduction in the average Dmax to spinal cord was observed for the plan with collimator angle 30 degree as compared to other angles. An increase in Dmax to spinal cord was observed for collimator angle 60 degree as compared to 0 degree. No clinically significant difference was observed among the plans with respect to brainstem and mandible Dmax. A slight reduction in brainstem average Dmean was seen at collimator angle 60 degree. The dose volume comparison curve of brainstem and spinal cord for a representative patient is shown in **Figure 2(b)**.

An increase in average of oral cavity Dmax and Dmean was observed for collimator angle 60 and 90 degree as compared to collimator angle 0 and 30 degree (**Table 1**). However, this difference is not clinically significant. The dose volume comparison curve of oral cavity and mandible for a representative patient is shown in **Figure 2(c)**.

Not much difference was observed with respect to Dmax and Dmean for contralateral parotid and cochlea with plans at different collimator angles (**Table 1**). As these structures were not directly shielded by the collimator, similar doses resulted with plans at different collimator angles. The dose volume comparison curve of contralateral parotid and cochlea for a representative patient is shown in **Figure 2(d)**.

The average of 2D  $\gamma$  index and MU required to deliver a plan with collimator angle 0 to 90 degree is shown in **Table 3**. A decrease in MU required to deliver a fraction was observed for the plan with collimator angle 30 degree as compared to other angles. The plan with 90 degree collimator required maximum MU.

The 2D  $\gamma$  index evaluation of planned and delivered fluence showed almost similar results for plans with different collimator angles. The 2D  $\gamma$  index analysis of IBA I'mRT MatriXX ionization chamber array measured fluence with the TPS calculated fluence of a representative patient for collimator angle 0 to 90 degree is shown in **Figure 3(a-d)**.

**TABLE 1:** The mean and standard deviation of the dose values for the target and organs at risk with plans at different collimator angles.

Structure	0°	30°	60°	90°
PTV Dmax (Gy)	64.38±1.68	64.84±0.74	64.81±0.92	64.86±1.29
PTV Dmean (Gy)	62.42±0.33	62.25±0.33	62.22±0.59	62.09±0.53
Spinal cord Dmax (Gy)	33.33±5.98	32.59±6.37	34.24±6.13	33.36±6.73
Brainstem Dmax (Gy)	28.77±2.53	28.99±2.45	28.32±2.47	28.12±4.75
Contra. Parotid Dmax (Gy)	13.94±6.89	14.23±7.17	14.11±6.97	14.11±7.29
Contra. Parotid Dmean (Gy)	6.52±2.19	6.55±1.93	6.71±1.86	6.80±1.82
Contra. Cochlea Dmax (Gy)	5.94±4.09	6.32±4.45	6.74±4.61	6.30±4.72
Contra. Cochlea Dmean(Gy)	4.15±3.59	4.63±4.30	5.02±4.02	4.59±4.10
Oral cavity Dmax (Gy)	50.02±10.58	50.68±10.96	51.70±9.18	58.73±7.02
Oral cavity Dmean (Gy)	20.13±5.71	20.80±6.32	21.32±6.78	21.18±6.71
Mandible Dmax (Gy)	63.99±0.57	63.94±0.60	63.98±0.89	63.71±0.62

Abbreviations: PTV = planning target volume; max = maximum; contra = contralateral

**TABLE 2:** The mean and standard deviation of the CI and HI values for the plans with respective collimator angles

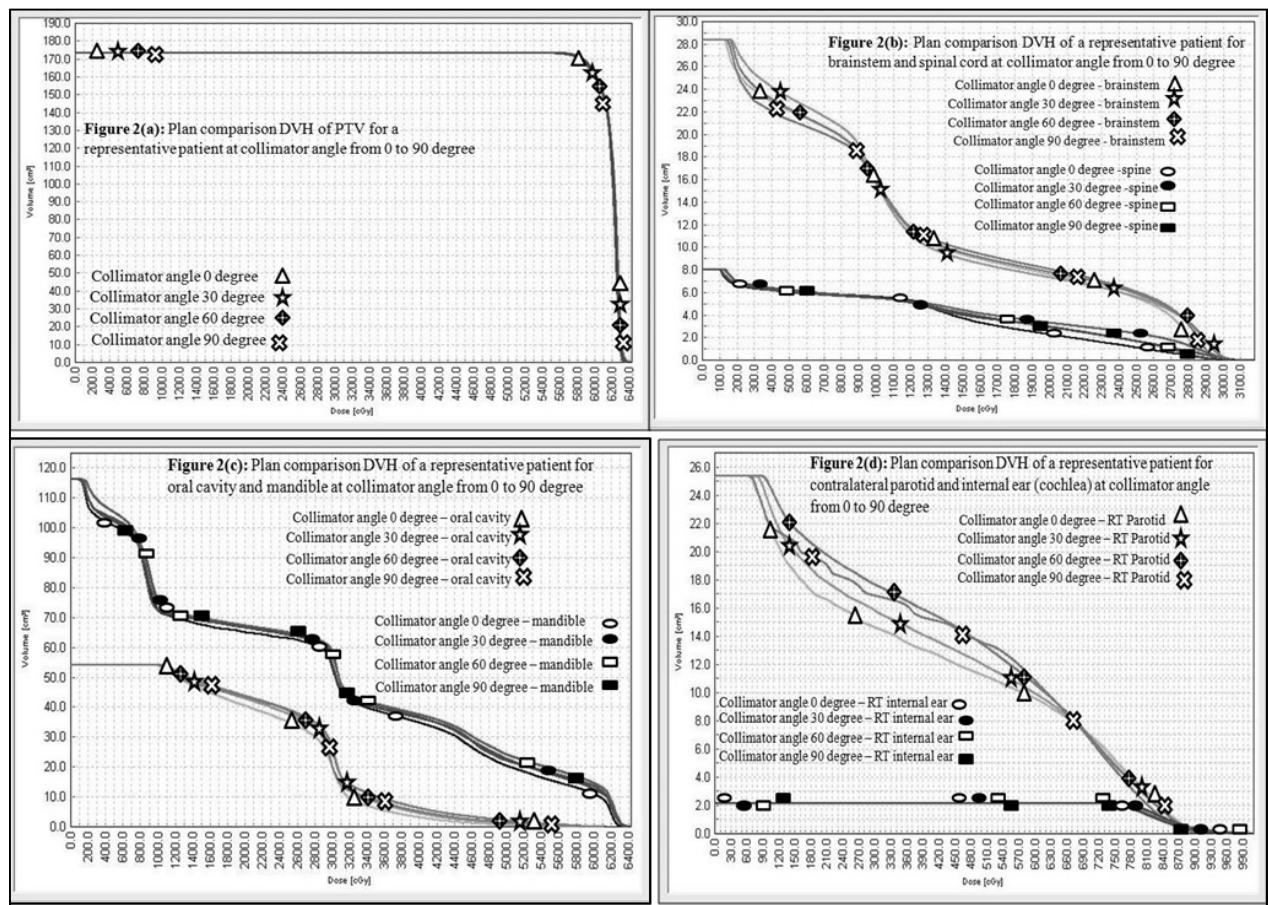
Index	0°	30°	60°	90°
CI	0.9140±0.004	0.8938±0.057	0.8967±0.045	0.8895±0.046
HI	1.0793±0.008	1.0797±0.012	1.0787±0.012	1.0805±0.013

Abbreviations: CI = conformity index; HI = heterogeneity index

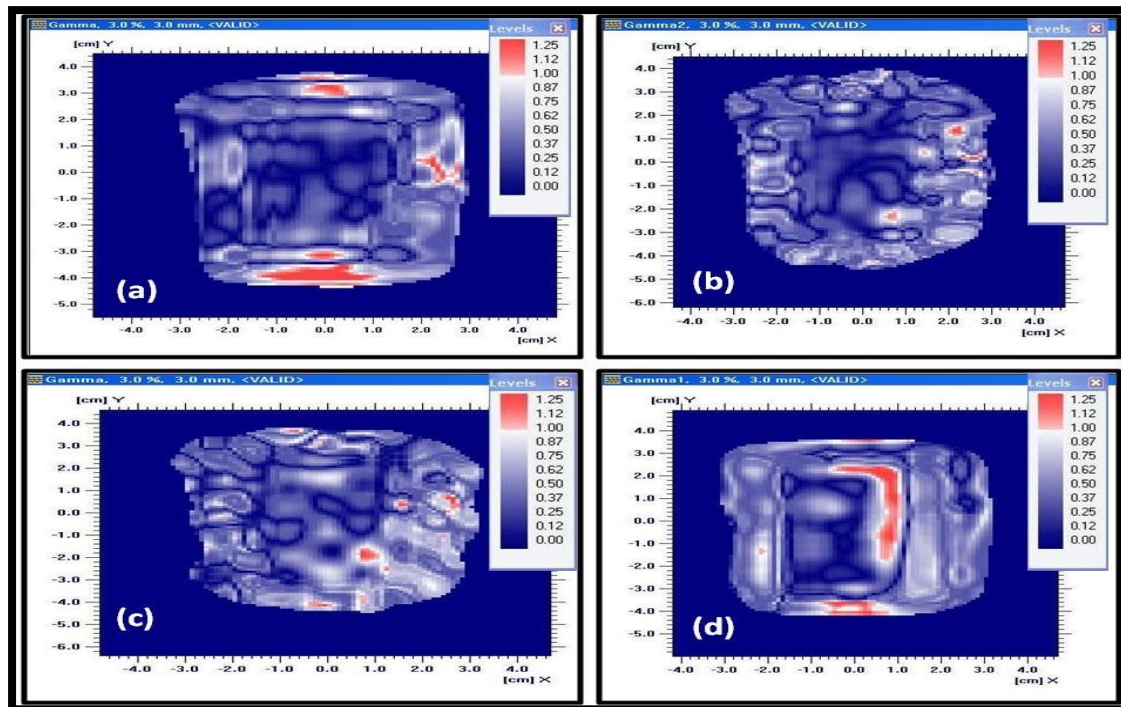
**TABLE 3:** The mean and standard deviation of the values of 2D  $\gamma$  index and MUs required to deliver a plan at the respective collimator angles

	0°	30°	60°	90°
$\gamma$ index	98.8±1.1%	98.8±1.6%	99.1±0.7%	99.1±0.8%
Total MUs	397±30	384±43	399±48	428±49

Abbreviations: MU = monitor units

**FIG. 2(a-d):** Plan comparison DVH of PTV and OAR's for a representative patient at collimator angle from 0 to 90 degree.





**FIG. 3(a-d):** The comparison of TPS calculated and I'matriXX measured 2D fluence gamma evaluation (3%/3 mm) result for a representative patient at collimator angle of (a) 0 degree, (b) 30 degree, (c) 60 degree, and (d) 90 degree.

## Discussion

The present study demonstrates that in terms of PTV coverage and plan homogeneity all collimator angles are comparable in IMRT planning for parotid cancer. The reduction in Dmax to spinal cord at the plan with collimator angle 30 degree illustrates that collimator rotation aids in delivering a conformal dose without increasing the dose to OARs. Moreover, proper selection of collimator angle according to the shape and curve of target and OARs is essential. A collimator angle may be superior for target coverage but may not be suitable for adjacent OARs. Therefore, while planning IMRT, collimator angle should be selected according to the beam's eye view for the particular gantry angle.

While delivering dynamic IMRT, the MLC leaves move under the jaws. At a specific collimator angle, the length of MLC moving under the jaws may be maximum which aids in reducing the inter- and intra-leaf transmission. This results in achieving a better dose distribution.<sup>13,14</sup> In terms of deliverability of modulated fluence with collimator rotation from 0 to 90 degree, no limitation was seen on the linear accelerator in the current study. Furthermore, a reduction in MU was observed at the plan with collimator angle 30 degree as compared to other angles.

Chapek *et al.*<sup>14</sup> elaborated on the addition of collimator parameter optimization i.e., both collimator angle and primary jaw settings to IMRT in prostate cancer. This resulted in a greater sparing of rectum as compared to intensity modula-

tion alone. However, the IMRT plan delivery with collimator rotation becomes complex. The potential dosimetric advantages of incorporating MLC rotation in IMRT were also investigated by Otto *et al.*<sup>15</sup> The results showed that higher spatial resolution dose distributions were attainable with the rotational technique, which resulted in superior target coverage and normal tissue sparing. It was also shown that inter-leaf leakage and tongue-and-groove effects were substantially reduced, decreasing the degree of systematic over-dosing and under-dosing observed in conventional IMRT delivery.

A study<sup>16</sup> highlighted the dosimetric issues which must be assessed before dynamic therapy with MLC can be implemented. The authors performed a series of calculations and measurements to quantify head scatter for small fields, collimator transmission, and the transmission through rounded leaf ends. These factors affected the delivered dose to the prostate by 5% to 20% for a typical plan. Thus, strict patient-specific pre-treatment plan quality verification and perfect dosimetric modeling of MLC is crucial after rotating the collimator.

## Conclusion

A variation in maximum dose to spinal cord was observed at IMRT plan with collimator angle 60 degree for parotid cancer. No clinically relevant difference was seen with respect to the dose to remaining critical structures, PTV coverage, and dose delivery by rotating the collimator from 0 to 90 degree.

An individual case-specific collimator rotation may aid in achieving the desired dose distribution and relative sparing of critical structures in IMRT.

## Conflict of interest

The authors declare that they have no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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